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IMPULSE DRYING OF LINERBOARD ON A SHEET-FED PILOT IMPULSE DRYING SHOE PRESS

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ABSTRACT

A wide range of one- and two-ply linerboard sheets have been impulse dried on a sheet-fed pilot impulse drying shoe press. The work, jointly conducted by the Institute of Paper Science and Technology (IPST) and Beloit Corporation, compared impulse drying to double-felted pressing for a wide range of process conditions.

This paper reports various performance indicators, including press dryness, STFI compression strength, and "printability" for impulse drying and double-felted pressing. The paper also reports the influence of such process variables as choice of press roll surface, impulse, and nip residence time.

These results confirm previously reported laboratory-scale results that impulse drying is superior to double-felted pressing and can result in substantial benefits with regard to product improvement, increased productivity, increased recycle utilization, and energy savings.

INTRODUCTION

Drying is the largest single energy use in the papermaking process accounting for about one quarter of the total energy used. Impulse drying was conceived to increase papermaking energy efficiency by reducing the amount of water to be removed by conventional evaporative drying.

Impulse drying occurs when a wet paper web passes through a shoe press nip in which the press roll is heated to a high temperature. A steam layer adjacent to the heated surface grows and displaces water from the sheet in a very efficient manner. As a result, the energy required for water removal is very much less than that required for conventional evaporative drying.

The increased dewatering during impulse drying allows improved productivity on existing machines which are dryer limited. In addition, impulse drying results in increased densification and thermal enhancement of sheet bonding to develop equivalent or superior products at lower cost. Cost reduction is possible via reduced basis weight, use of higher yield or higher recycle content furnishes, and reduced refining.

One of the major reasons for implementing impulse drying in the production of board grades is that impulse drying technology is an extension of shoe press technology. Almost all shoe presses installed throughout the world have been installed on machines producing board grades. Additionally, a large fraction of the paper manufactured in the United States is comprised of board grades.

It is expected that the introduction of impulse drying into the board grade market will parallel the introduction of shoe presses. Ten years after first being introduced in the early 1980s, shoe presses accounted for about 52% of United States and about 48% of world production of board grades. Using the rate of introduction of shoe presses as a basis, and historical average production growth rates, it is estimated that yearly U.S. energy savings could increase to more than 0.84 x 10^{17}J (0.08 x 10^{15}Btu) within 30 years after impulse drying is first introduced.

A troublesome component of the impulse drying process is sheet delamination [1]. As the nip depressurizes, subcooled liquid water remaining in the sheet flashes to vapor and escapes through the heated surface of the sheet. When excessive amounts of energy are transferred to the sheet, drag forces resulting from the escaping vapor can be high enough to overcome the cohesive forces holding the sheet together, and the sheet delaminates.

Controlling energy transfer to the sheet helps prevent sheet delamination. Low "thermal mass" press roll coatings have been developed to reduce heat transfer to the sheet while maintaining high surface temperatures during early stages of the process. This ensures that most of the transferred energy is used to form steam that displaces liquid water, while excessive steam formation, leading to delamination, is avoided.

LITERATURE REVIEW

Early Laboratory-scale Experiments

Early laboratory-scale work with a machinable ceramic showed that sheet exit temperatures were reduced by replacing the steel platen with a low "thermal mass" ceramic [2-4]. Internal sheet temperatures were measured during impulse drying by thermocouples placed at various locations within the linerboard sheet. A steel platen resulted in internal sheet temperatures in excess of 100°C in as short as 10 milliseconds. In contrast, the machinable ceramic restricted heat transfer to the sheet so that internal sheet temperatures were substantially reduced.

Using a more practical plasma sprayed ceramic coated platen, water removal was found to be dependent on initial temperature and impulse while being independent of platen thermal properties [4]. This suggested that high water removal rates could be maintained while reducing excessive energy transfer to the sheet.

In the same experiments, critical impulse drying temperature, above which sheet delamination occurs, was found to be influenced by platen thermal properties and by peak pressure (impulse). It was shown that the ceramic surface could be operated at higher temperatures and pressures than the steel platen without inducing sheet delamination. As a result, more water could be removed from the sheet.

To help explain this effect, additional experiments were conducted in which surface thermocouples were used to determine how platen thermal properties affect energy transfer to the sheet [5]. It was determined that energy transfer was dependent on peak pressure (impulse) for high "thermal mass" steel surfaces while being virtually independent of peak pressure (impulse) for the low "thermal mass" ceramic coated platen. It was also observed that at a given temperature, and impulse, the ceramic surface transfers less energy to the sheet than the steel platen. Hence, it was postulated that ceramic surfaces avoid sheet delamination by decoupling heat transfer from wet pressing effects. As a result, the ceramic surface can be operated at higher pressures without overheating the sheet. Concurrently, by transferring less energy, the ceramic surfaces can be operated at higher temperatures.

Impulse dried under these conditions, sheet density could be increased to higher levels resulting in higher strength as measured by elastic modulus, STFI compression strength, and burst strength. While ceramic surfaces achieve higher density, the relationship between bond strength (specific elastic modulus) and sheet density was independent of platen material.

Roll Press Research

In 1991, impulse drying research shifted to demonstrating the process on a pilot roll press. The internal structure of the plasma sprayed ceramic roll coating was similar to that of the earlier platen experiments. The ceramic coating had an effective "thermal mass" of 2000 $W \cdot s^{1/2}/m^{2} \cdot °C$. The roll was heated by an external source of infrared radiation as controlled by an infrared sensor.

Pilot experiments performed at ingoing solids of less than about 40% resulted in outgoing solids not significantly above that which could be obtained from conventional pressing technology. At ingoing solids above 40%, substantial improvements over conventional pressing were demonstrated. An objective of the pilot trials was to determine the influence of furnish variables on impulse drying performance. Sheet permeability was investigated since it influences conventional pressing processes. The out-of-plane permeability of single-ply liner board was measured over a range of refining and pressing conditions [6]. From permeability vs. sheet porosity data, hydraulic specific surface was determined. A low specific surface means that the sheet is highly permeable. Increased refining increases specific surface, while pressing decreases specific surface.

Permeability measurements were made on two different liner board furnishes [7] refined to freeness from 550 ml CSF to 740 ml CSF and pressed to 42% solids prior to testing. The single-ply linerboard sheets for both furnishes were impulse dried on a pilot roll press. It was found that critical impulse drying temperature decreased with increased specific surface [6,7]. Comparison of impulse drying, at the critical temperature, to single-felted pressing, at the same impulse, showed that the maximum benefit from impulse drying occurred when specific surface was minimized.

Water removal was dependent on press surface temperature, impulse, and the specific surface of the sheet. Likewise, energy transfer during impulse drying was only dependent on press surface temperature [7,8].

Laboratory-scale Research

As commercial board grades are often produced as multi-ply sheets, containing recycled fiber, recent research was directed at applying impulse drying to these commercially important sheet structures. Toward this end, laboratory-scale simulations were used to identify important pulp substitution variables and quantify the benefit of impulse drying [9].

Commercial linerboard is usually two or three ply and composed of blends of virgin Kraft and recycled fiber. In current practice, the amount of recycled fiber included in linerboard is limited by the fact that sheet strength properties decrease when recycle content is increased. To achieve acceptable strength, mills either limit recycle content or further refine the recycle fiber which negatively impacts water removal and thus machine speeds.

Recycled fiber has the additional disadvantage that it has an unacceptable physical appearance. To improve the appearance of liner, made with recycle fiber, U.S. manufacturers form a multi-ply sheet where recycled fiber is contained in a bottom or inner layer, and outer layers are made from virgin pulp sufficiently refined to impart a good appearance to the product.

The experimental program was conducted in three experimental groups. In the first grouping, pulp species and Kappa number were investigated. In the second grouping, blends of virgin Kraft and OCC were investigated. While in the third group of experiments, the influence of the composition and freeness of both top and bottom plies was investigated. In all cases, the total basis weight of the sheets was kept at 205 g/m^2 (42 $lb_f/1000ft^2$).

The hydrodynamic specific surface of single component single-ply sheets may be expressed as a function of their Canadian standard freeness. High Kappa southern pine tended to be more permeable at a given freeness than low Kappa southern pine. In contrast, the low Kappa Douglas fir was more permeable than high Kappa Douglas fir. Contrasting the southern pine and Douglas fir at high freeness, it was observed that the southern pine tends to be more permeable.

Hydrodynamic specific surface vs. freeness was also measured for the recycled OCC furnish. The specific surface of two component blends of high Kappa southern pine with OCC was also measured as a function of the OCC content. Since specific surface was not a linear function of OCC content, as much as 60% OCC by weight could be added without the specific surface increasing beyond 5 m^2/g.

The electrohydraulic press was used to simulate double-felted pressing and impulse drying of preheated sheets having ingoing solids of 52%. Use of a programmable signal generator allowed the electrohydraulic press to simulate a pressure history that the sheet would experience in a commercial impulse dryer configured on a shoe press.

Critical impulse drying temperature was reported as a function of hydrodynamic specific surface. For single-ply sheets, the hydrodynamic specific surface was the measured value. For two-ply sheets, the hydrodynamic specific surface was taken to be that of the surface of the sheet in contact with the heated platen. Critical impulse drying temperature results compared well with previous results obtained on a pilot roll press [7]. In addition, double-ply and single-ply data were consistent, suggesting that the hydrodynamic specific surface of the layer in contact with the heated platen controls delamination.

Outgoing solids for single-ply sheets made from high Kappa southern pine and old corrugated containers showed that impulse drying had a press dryness advantage over double-felted pressing for OCC content below 60% by weight.

Outgoing solids for double-ply sheets showed that impulse drying was superior to double-felted pressing independent of the top heated-ply freeness. For the case when the bottom unheated-ply was made from 100% OCC at 600 ml CSF, impulse drying was superior when the top ply freeness was more than 600 ml CSF.

Many linerboard manufacturers use the cross direction STFI compression strength as the target strength parameter used to adjust their processes. Hence, the higher the CD STFI Index the better. CD STFI Index was reported as a function of OCC content for single-ply sheets made from high Kappa southern pine and old corrugated containers. Impulse drying CD STFI Index was superior to that of double-felted pressing as long as OCC content was below 50%. Comparing the CD STFI Index obtained by impulse drying to that of the control shows that impulse drying has a benefit over conventional papermaking independent of OCC content.

CD STFI Index was also reported as a function of hot side freeness for double-ply sheets. When the bottom ply was made from a 50%:50% blend of high Kappa southern pine at 750 ml CSF and OCC at 600 ml CSF, impulse drying CD STFI Index was superior to that of double-felted pressing when hot side freeness was greater than 550 ml CSF. When the bottom ply was made from 100% OCC at 600 ml CSF, impulse drying CD STFI Index was equal or superior for the entire range of hot side freeness. Impulse drying always resulted in superior strength as compared to the control.

OBJECTIVES

Using the same pulp evaluated in laboratory simulation experiments, comparable experiments were conducted on a sheet-fed pilot-scale shoe press [10]. In these experiments two roll coatings were evaluated. The coatings are herein designated by the letters C and A.

The objectives of the experiments were

1. to compare the performance of the C and A press roll surface coatings,

2. to obtain process data over a wide range of linerboard sheet structures, and

3. to evaluate the resulting linerboard in terms of important physical properties.

Laboratory-scale experiments had identified a methodology for structuring sheets so that they could be successfully impulse dried. The present experiments were designed to confirm the scale-up of that methodology to conditions more representative of commercial conditions. Single- and double-ply sheet structures were chosen that made use of southern pine, Douglas fir, and OCC pulps. Those structures were also chosen to span a wide range of hydrodynamic specific surface.

Additional objectives of the present experiments were to compare impulse drying to double-felted, single-felted hot pressing and to unpressed controls.

RESULTS

The pilot experiments were conducted at Beloit Corporation's Rockton, Illinois, research laboratory. An X2 pilot shoe press on paper machine #2, as shown in Figure 1, was used.

In order to meet the stated objectives, the experimental conditions as shown in Table 1 were established. These conditions represent the cases that were run for each of six furnishes spanning a wide range of hydrodynamic specific surface.

The pulp used in these experiments were taken from the same batch used in conducting the laboratory-scale experiments [9]. Table 2 shows the composition of the six furnishes that were to be investigated. Furnishes with the prefix WF were produced on a low-speed web former, while furnish cases having a FD prefix were produced on a Formette Dynamique at conditions similar to those used in the earlier work [9].

For each furnish, fiber analysis was performed on samples of the prepared sheets. The results of the fiber identification are in Table 3. Table 4 summarizes the average fiber dimensions. The measured hydrodynamic specific surfaces for each furnish are in Table 5.

Critical temperatures for each impulse drying case were determined from ultrasound measurements and by visual observation. Table 6 lists the critical temperatures and their uncertainties. These are consistent with those previously measured in laboratory-scale simulations [9].

Figures 2 through 7 show outgoing solids as a function of furnish for each of the process variables. Note that the furnishes are arranged in order of increasing hydrodynamic specific surface. In these, and subsequent figures, the legend symbols are used to identify the method of pressing used and the process case. For example, (D1) indicates that the data correspond to double-felted pressing at Case 1 process conditions. Similarly, (C2) and (A2) correspond to impulse drying at Case 2 process conditions using the C and A press roll surfaces, respectively.

It was observed that impulse drying was always superior to double-felted pressing in achieving outgoing solids. In addition, there was evidence that the A roll surface resulted in higher outgoing solids than the C surface.

In a similar way, Figure 8 shows the effect of increasing the machine speed of the impulse dryer from 365 m/min (1200 ft/min) to 457 m/min (1500 ft/min) (or reducing nip residence time from 40 ms to 30 ms). For the conditions investigated, the speed increase resulted in an outgoing solids reduction of about 1%. Figure 8 also shows the effect of using "hard" felt washwater in place of deionized felt washwater. It was observed that the use of "hard" felt washwater tended to increase outgoing solids. It may be speculated that this may have been caused by longer postnip contact between the press roll and the sheet when calcium carbonate may have accumulated on the roll surface.

Figures 9 through 14 show the geometric mean STFI indexes for Case 1 through Case 6, comparing double-felted pressing (D) to impulse drying with the C press roll (C), and to impulse drying with the A press roll (A). The STFI compression strength of impulse dried sheets tended to be higher or equal to that achieved by double-felted pressing, while differences due to press roll surface were not statistically significant.

In addition to STFI compression strength, other important physical properties were measured on double-felted and single-felted pressed samples and on samples impulse dried at the critical temperature. These properties were Sheffield and Bendtsen roughness, Gurley porosity, Cracking angle, Ink penetration, z-direction tensile, and Burst.

Selected handsheets from the pilot shoe press experiment were also printed on a commercial flexographic printing press and evaluated for print quality.

The sheets were printed at the same conditions using undiluted, black, flexographic ink. The printed image consisted of at least one solid black region which could subsequently be analyzed for print mottle.

Image analysis was used to evaluate the "unprinted" and "solid printed" areas of the sheet. For each area, the normalized number of pixels having "gray scale readings" of 0 to 265 was determined. Here, a gray scale reading of 0 corresponds to white, while a gray scale reading of 265 corresponds to black. From the gray scale frequency distributions, cumulative distributions were generated as shown in Figures 15 through 23.

Figures 15 through 17 characterize the printed and unprinted areas of two-ply sheets composed of a 740 ml CSF freeness virgin Kraft on the printed ply and a 50/50 blend of 740 ml CSF Virgin Kraft and 600 ml CSF OCC in the bottom ply. Figure 15 shows the double-felted pressed case, while Figures 16 and 17 show single-felted pressed and impulse dried cases, respectively. The curves for the unprinted areas can be used to quantify the contrast of the black ink to the unprinted sheet, while the curves for the solid printed areas can be used to quantify print mottle.

Figures 18 through 20 characterize the printed and unprinted areas of single-ply sheets composed of 450 ml CSF OCC. Figure 18 shows the double-felted pressed case, while Figures 19 and 20 show single-felted pressed and impulse dried cases, respectively.

Figures 21 through 23 characterize the printed and unprinted areas of single-ply sheets composed of 740 ml CSF Virgin Kraft. Figure 21 shows the double-felted pressed case, while

Figures 22 and 23 show single-felted pressed and impulse dried cases, respectively.

CONCLUSIONS

In summary, the major conclusions to be drawn from the pilot shoe press experiments may be listed as:

Press Roll Surface Strength: The C roll coating was susceptible to chipping under shear, while the A roll did not chip.

Critical Impulse Drying Temperature: As in previous experiments [9], critical impulse drying temperature was found to depend on the hot side hydrodynamic specific surface. As expected, critical impulse drying temperature was higher for the "low thermal mass" C press roll than for the "higher thermal mass" A press roll. Interestingly, it was also concluded that the choice of felt influenced the critical temperature.

Press Dryness : For a given set of pressing conditions, press dryness tended to decrease when the hydrodynamic specific surface of the sheet increased. In addition, press dryness resulting from impulse drying was generally higher than that achieved by double-felted pressing. Differences in dryness ranged from 8 percentage points for sheets having low hydrodynamic specific surface to 3 percentage points for less permeable sheets. The A roll yielded higher press dryness than the C roll, even though it was generally operated at lower temperature. Increasing the press load from 1050 kN/m (6000 lb_f/in) to 1489 kN/m (8500 lb_f/in) increased press dryness.

STFI Compression Strength: The geometric mean STFI compression strength of impulse dried sheets was consistently higher than that obtained by double-felted pressing. The difference in strength tended to be more significant for the more permeable sheet structures. For two-ply sheets, the STFI compression strength resulting from impulse drying was as much as 17 percent higher than that produced by double-felted pressing. No substantial strength difference was observed comparing sheets impulse dried with the two press rolls.

Felt Water Chemistry : Using "hard" felt wash water tended to increase outgoing solids by up to about 3 percentage points. STFI Index, however, was not influenced by water chemistry.

Speed Effects: Decreasing nip residence time had the expected result of decreasing water removal and STFI compression strength for all furnishes.

Gurley Porosity : For all furnishes, the impulse dried sheets were less porous than double-felted pressed sheets, which in turn were less porous than the control sheets.

Ink Penetration Test : The rate of change of the contact angle for black flexographic ink drops on the felt side of the samples was measured. The measurements were generally independent of furnish and method of pressing and were similar to measurements of commercial samples.

Sheet Surface Macro Roughness : The macro roughness of the hot side of sheets was measured by Sheffield and Bendtsen roughness tests. While the method of pressing and the extent of refining control surface macro roughness, the method of pressing was the dominant variable. In general, impulse dried samples were smoother than single-felted pressed samples, which in turn were smoother than double-felted pressed samples.

ZD Tensile : The zd tensile strength is a measure of ply-bond strength. Impulse drying tended to significantly increase zd tensile strength.

Burst Index : Impulse drying tended to increase burst strength as compared to double-felted pressing.

Cracking Angle : Cracking angle was found to be dependent on the level of refining of the fibers on the hot side of the sheet and the method of pressing. Refining was found to be the dominant effect, in that excessive refining leads to a low cracking angle. Impulse dried samples tended to have slightly lower cracking angles than double- or single-felted pressed sheets. As impulse drying performs best when the heated ply is not heavily refined, there should be no problem in achieving acceptable cracking angle in commercial practice.

Print Mottle : Double-felted pressed sheets tended to have the worst print mottle, while that exhibited by impulse dried sheets was equal to or better than that of single-felted pressed sheets. Impulse drying was observed to darken the sheet. As an observer will primarily evaluate sheet quality on mottle rather than contrast, impulse drying will positively impact print quality relative to double-felted pressing.

FUTURE WORK

These shoe press experiments have set the stage for a renewed interest in attempting continuous commercial speed pilot-scale demonstration of impulse drying for linerboard. It is recommended that impulse drying proceed toward commercialization. In the mean time, there are still technical issues that must be resolved.

Shoe press experiments have demonstrated that the C ceramic roll coating is susceptible to shear failure when the roll operates at temperatures between 100 and 150°C. Photomicrography of the failure zones confirmed that these failures occurred when paper that had adhered to the roll was subjected to shear at the doctor blade. While the A roll is intrinsically stronger, and did not experience failure, the issue of roll surface long-term durability clearly requires further study. For this purpose, an analytical modeling effort was initiated that will lead to the prediction of stress and temperature as a function of position and time in the various layers of a commercial impulse drying press roll.

Through a grant from the Electric Power Research Institute, IPST has designed a modification to its existing pilot impulse dryer to allow it to function as a press roll durability test stand. The U.S. Department of Energy has funded the construction, instrumentation, and operation of the durability test stand.

The heated roll will be driven at 762 m/min (2500 ft/min) and loaded against a felt that has been saturated with water to provide a heat sink similar to that provided by paper in impulse drying. The roll surface will be continuously monitored by infrared thermography to detect the onset of surface flaws in the coating. In addition, the state of strain on the roll surface will be measured using three-dimensional speckle interferometry. These surface strains will then be used with experimental stress-strain data to determine surface stresses. These experimental surface stresses will then be compared to the predictions of the finite element model.

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Table 1. Experimental Conditions.

Case	Conditions: Pressing Type	Roll Cover	Felt	Pivot	Speed (m/min)	Load (kN/m)	Wash Water
Con	Control	n/a	n/a	n/a	n/a	n/a	n/a
D1	D.F.	n/a	B	0	365	1050	Deionized
D2	D.F.	n/a	B	0	365	1489	Deionized
D3	D.F.	n/a	B	+2	365	1050	Deionized
D4	D.F.	n/a	S	0	365	1050	Deionized
D5	D.F.	n/a	S	0	365	1489	Deionized
D6	D.F.	n/a	S	+2	365	1050	Deionized
C1S	S.F.	C	B	0	365	1050	Deionized
C2S	S.F.	C	B	0	365	1489	Deionized
C3S	S.F.	C	B	+2	365	1050	Deionized
A1S	S.F.	A	B	0	365	1050	Deionized
A4S	S.F.	A	S	0	365	1050	Deionized
A5S	S.F.	A	S	0	365	1489	Deionized
C1	I.D.	C	B	0	365	1050	Deionized
C2	I.D.	C	B	0	365	1489	Deionized
C3	I.D.	C	B	+2	365	1050	Deionized
A1	I.D.	A	B	0	365	1050	Deionized
A2	I.D.	A	B	0	365	1489	Deionized
A4	I.D.	A	S	0	365	1050	Deionized
A5	I.D.	A	S	0	365	1489	Deionized
A6	I.D.	A	S	+2	365	1050	Deionized
A5F	I.D.	A	S	0	457	1489	Deionized
A4H	I.D.	A	S	0	365	1050	"Hard"
A5H	I.D.	A	S	0	365	1489	"Hard"

Notes:

Roll surface temperatures typically: 6 temperatures at 25°C intervals.
All sheets to have ingoing solids of 52%.
Repeats typically to 4 per case.
All sheets to be steamed prior to impulse drying or double-felted pressing.

Table 2. Furnish Compositions.

	Composition of Top Ply			Composition of Bottom Ply		
Furnish Case	Pulp Type	Freeness ml	Weight %	Pulp Type	Freeness ml	Weight %
WF1	HKSP	740	100			0
WF2	HKSP	600	100			0
WF3	HKDF	720	100			0
FD5	OCC	450	100			0
FD6	HKSP	740	20	HKSP OCC	740 600	40 40
FD7	HKDF	720	20	HKDF OCC	720 600	40 40

Table 3. Fiber Identification for Various Pulp Samples.

Furnish	Pulp Type	USWK %	UHWK %	Softwood Species	Hardwood Species
WF1	S.Pine High Kappa	97-98	2-3	Southern yellow pine (Hard Cook) Trace of Semibleached Kraft	Mixed, incl. Gum, Yellow Poplar, and Oak
WF2	S.Pine High Kappa	97-98	2-3	Southern yellow pine (Hard Cook) Trace of Semibleached Kraft	Mixed, incl. Gum, Yellow Poplar, and Oak
WF3	D.Fir High Kappa	100(-)	Trace	Douglas Fir, Ponderosa and/or Lodgepole pine, Balsam Fir, Hemlock, Trace of Cedar and White Pine (Hard Cook)	Alder
FD5	OCC	n/a	n/a	Mixed Unbleached Kraft, and Semibleached Kraft	Mixed Kraft, Unbleached Semichemical Kraft, NSSC Pulps, and Mechanical Pulps
FD6	HKSP & OCC	90-95	5-10 & semi-chem.	Mixed Species incl. Hard Pine (Southern Yellow Pine, Ponderosa Pine, and/or Lodgepole Pine, etc.), Douglas Fir, Balsam Fir, Hemlock	Mixed, incl. Gum, Oak, Yellow Poplar, and Maple
FD7	HKDF & OCC	90-95	5-10 & semi-chem.	Mixed Species incl. Hard Pine (Southern Yellow Pine, Ponderosa Pine, and/or Lodgepole Pine, etc.), Douglas Fir, Balsam Fir, Hemlock	Mixed, incl. Gum, Oak, Yellow Poplar, and Maple

Table 4. Fiber Dimensions.

Furnish Case	Pulp Type	Kappa No.	Top Ply Freeness (ml CSF)	Length (mm)			Width (mm)	Perimeter (mm)	Cell Wall Thickness (mm)	Coarseness (mg/100 m)
				Arith	LW	WW				
WF1	S.Pine	109.2	740	2.52	3.21	3.73	36.6	87.2	3.5	36.0
WF2	S.Pine	109.2	600	1.78	2.47	3.07	34.8	83.7	3.5	34.2
WF3	D.Fir	89.6	720	1.95	2.71	3.31	33.1	74.6	2.1	24.2
FD5	OCC	114.6	450	1.00	1.44	2.07	27.9	68.3	3.1	29.2
FD6	S.Pine &OCC	n/a	740	1.80	2.68	3.43	33.7	79.8	3.1	29.4
FD7	D.Fir &OCC	n/a	720	1.66	2.52	3.20	34.5	78.6	2.4	26.8

Table 5. Hydrodynamic Specific Surface.

Furnish Case	Specific Surface (m^2/g)	Standard Deviation	Specific Volume (cm^3/g)	Standard Deviation
WF1	1.3	0.5	1.0	0.2
WF2	3.1	0.7	1.1	0.1
WF3	2.3	0.8	1.1	0.1
WF4	1.3	0.2	1.1	0.0
WF5	1.8	0.2	1.2	0.0
FD5	10.5	0.6	1.0	0.0
FD6	1.4	0.2	1.2	0.1
FD7	2.0	0.3	1.1	0.0

Table 6. Critical Temperatures (In Degrees Celsius) for Impulse Drying on the X2 Shoe Press with Upper and Lower Uncertainties.

Case	Description	WF1	WF2	WF3	FD5	FD6	FD7
C1	IPST-C/ Felt B/ 0 Pivot/ 1050 kN/m	245 +50 -0	195 +50 -0	195 +50 -0	155 +35 -0	240 +50 -0	240 +50 -0
C2	IPST-C/ Felt B/ 0 Pivot/ 1489 kN/m	245 +50 -50	245 +50 -0	195 +50 -0	150 +45 -50	245 +50 -0	150 +45 -0
C3	IPST-C/ Felt B/ +2 Pivot/ 1050 kN/m	150 +50 -50	150 +50 -0	150 +50 -0	145 +55 -45	245 +50 -0	245 +50 -45
A1	Beloit-A/ Felt B/ 0 Pivot/ 1050 kN/m	200 +55 -0	175 +25 -0	175 +25 -35	145 +55 -0	200 +55 -0	145 +55 -0
A2	Beloit-A/ Felt B/ 0 Pivot/ 1489 kN/m	200 +55 -0	175 +25 -0	175 +25 -35	120 +25 -0	200 +55 -0	145 +55 -0
A4	Beloit-A/ Felt S/ 0 Pivot/ 1050 kN/m	155 +55 -0	155 +55 -0	155 +55 -0	130 +25 -0	130 +25 -0	155 +55 -0
A5	Beloit-A/ Felt S/ 0 Pivot/ 1489 kN/m	155 +55 -0	155 +55 -0	155 +55 -0	100 +30 -0	155 +55 -0	130 +25 -0
A6	Beloit-A/ Felt S/ +2 Pivot/ 1050 kN/m	150 +25 -0	150 +25 -0	150 +25 -0	120 +30 -0	150 +25 -0	150 +25 -0
A4F	Beloit-A/ Felt S/ 0 Pivot/ 1050 kN/m/ 30 ms	<150	<150	<150	<150	<150	<150
A5F	Beloit-A/ Felt S/ 0 Pivot/ 1489 kN/m/ 30 ms	175 +25 -0	150 +25 -0	150 +25 -0	100 +50 -0	175 +25 -25	150 +25 -50
A4H	Beloit-A/ Felt S/ 0 Pivot/ 1050 kN/m/ hard water	175 +• -0	175 +• -0	150 +25 -0	100 +50 -0	175 +25 -0	150 +25 -0
A5H	Beloit-A/ Felt S/ 0 Pivot/ 1489 kN/m/ hard water	150 +25 -0	150 +25 -0	150 +25 -0	100 +50 -0	175 +25 -25	150 +25 -0

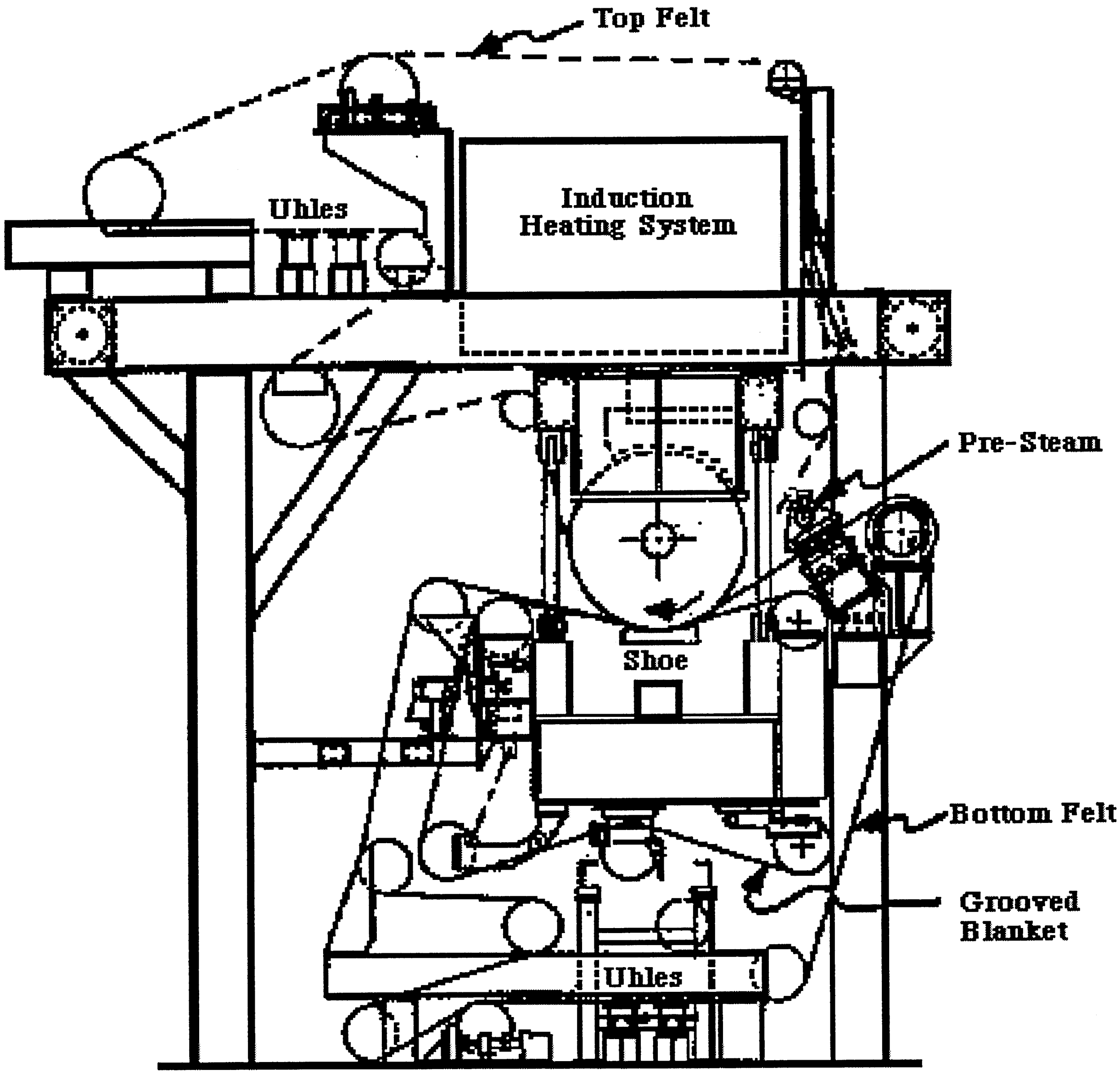

Figure 1. Pilot Shoe Press Configured for Impulse Drying, Double-felted or Single-felted Pressing.

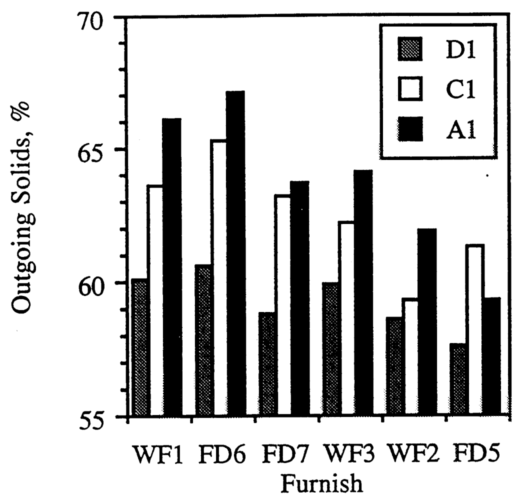

Figure 2. Outgoing Solids for Case 1.

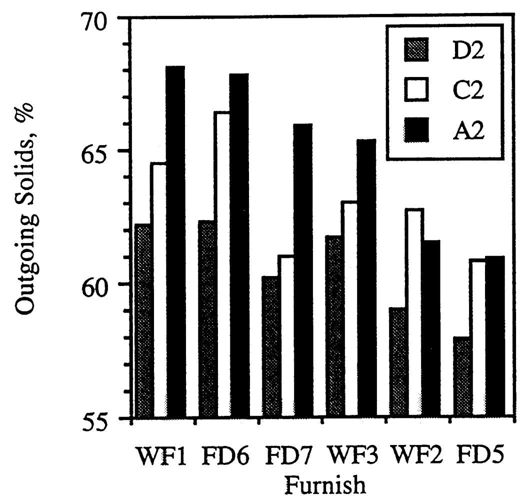

Figure 3. Outgoing Solids for Case 2.

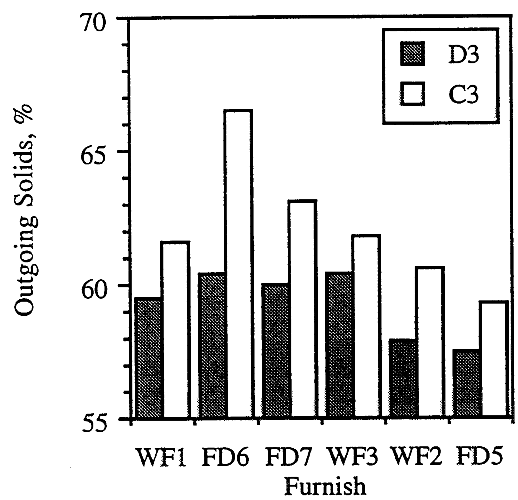

Figure 4. Outgoing Solids for Case 3.

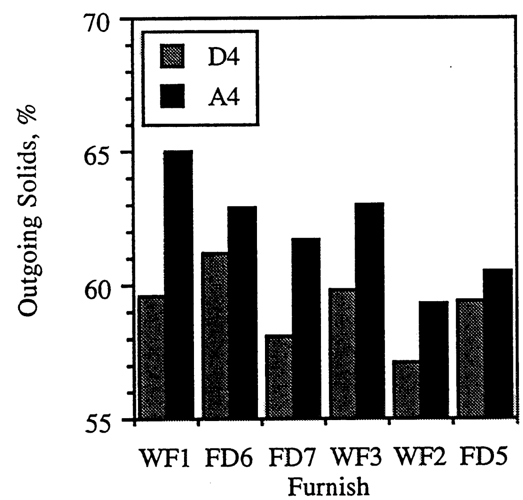

Figure 5. Outgoing Solids for Case 4.

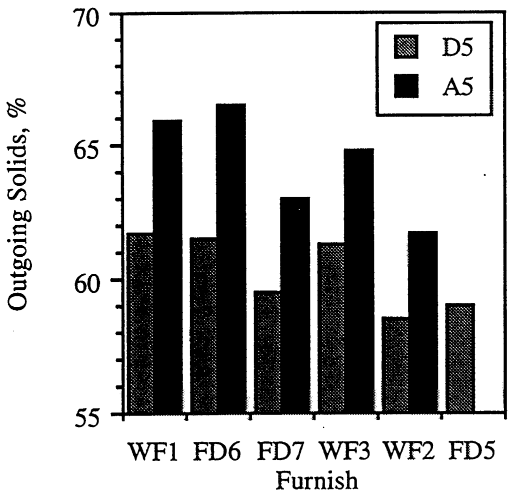

Figure 6. Outgoing Solids for Case 5.

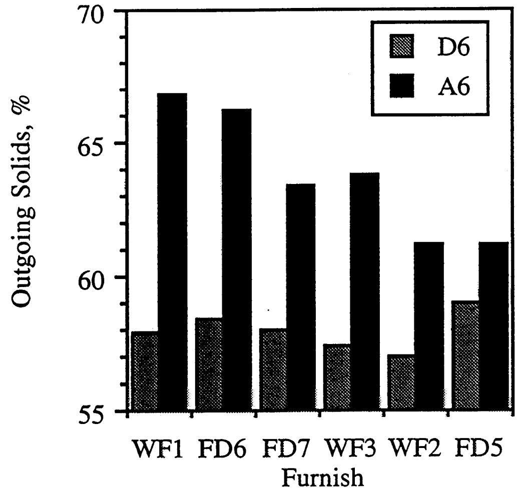

Figure 7. Outgoing Solids for Case 6.

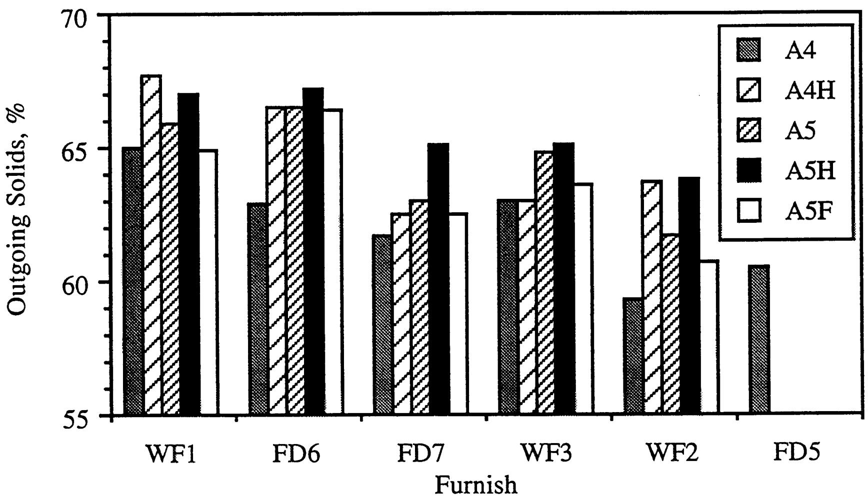

Figure 8. The Effect of Machine Speed and Felt Washwater Hardness on Outgoing Solids Case 4 and Case 5 Using the A Press Roll.

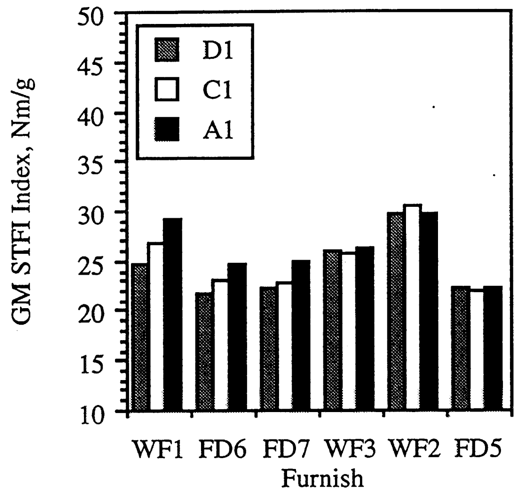

Figure 9. GM STFI Index for Case 1.

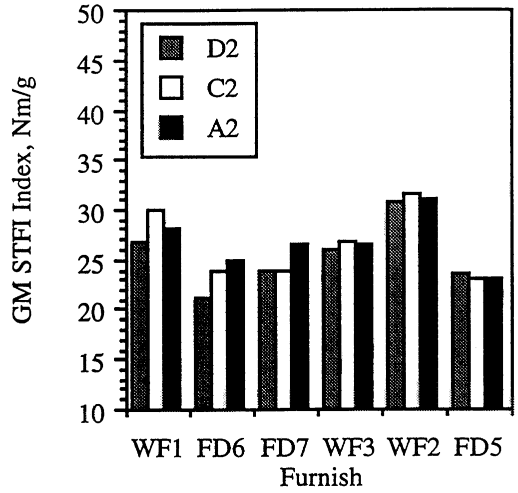

Figure 10. GM STFI Index for Case 2.

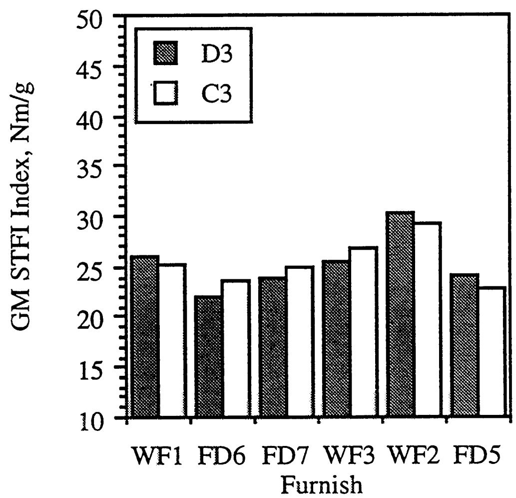

Figure 11. GM STFI Index for Case 3.

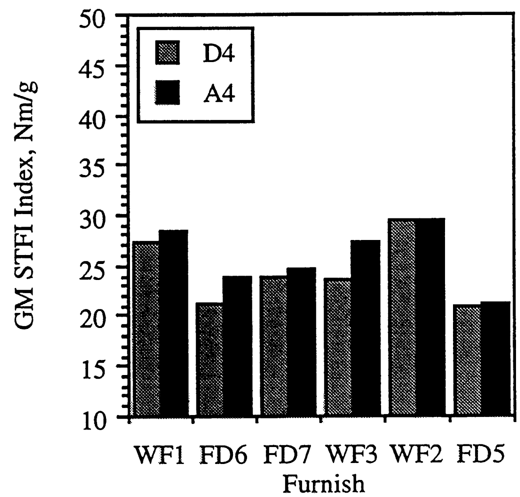

Figure 12. GM STFI Index for Case 4.

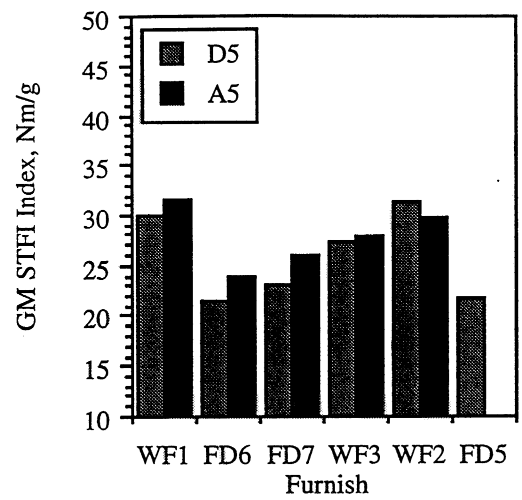

Figure 13. GM STFI Index for Case 5.

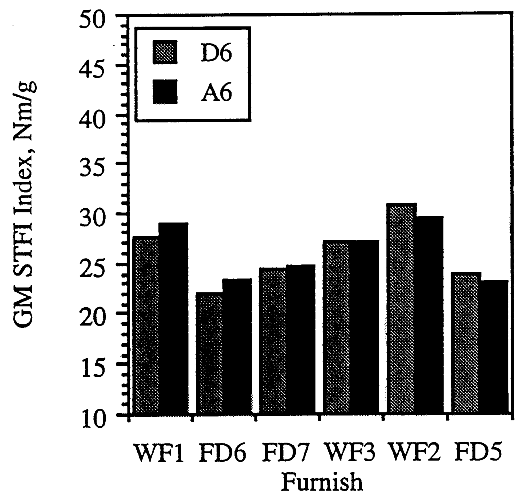

Figure 14. GM STFI Index for Case 6.

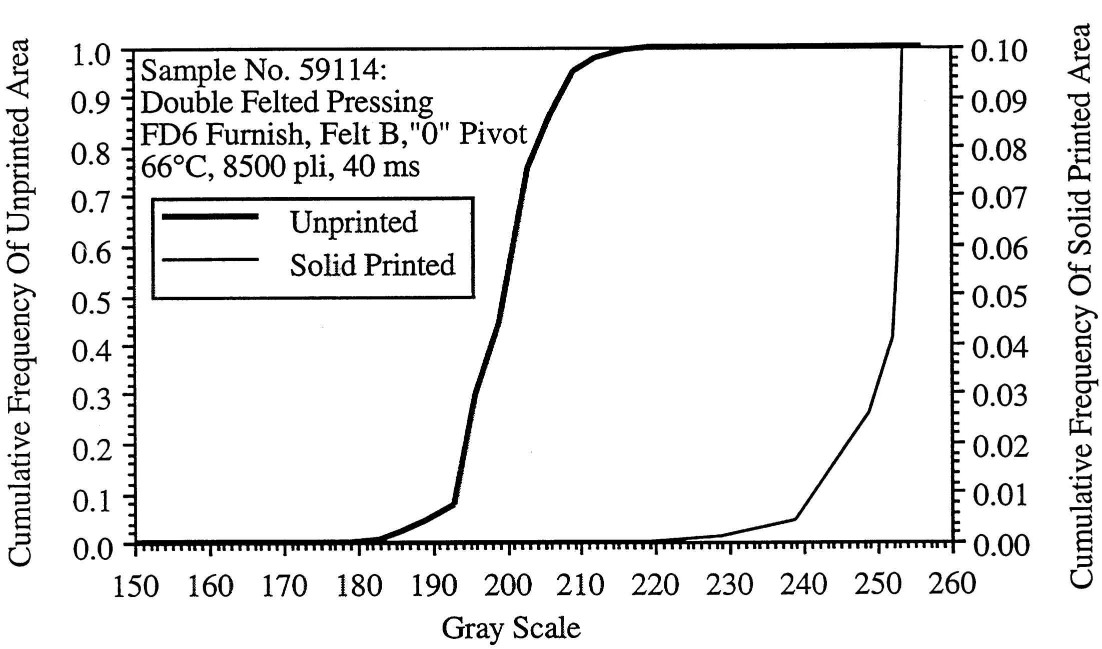

Figure 15. Cumulative Frequency vs. Gray Scale for Printed and Unprinted Regions of a Two-ply Sheet Which Had Been Double-felted Pressed.

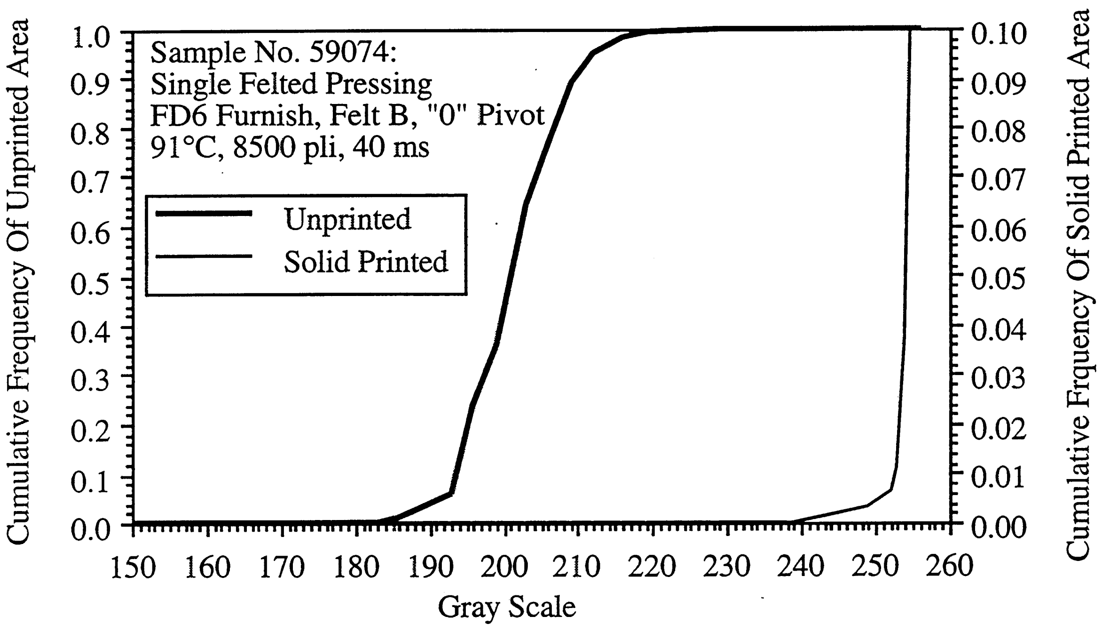

Figure 16. Cumulative Frequency vs. Gray Scale for Printed and Unprinted Regions of a Two-ply Sheet Which Had Been Single-felted Pressed.

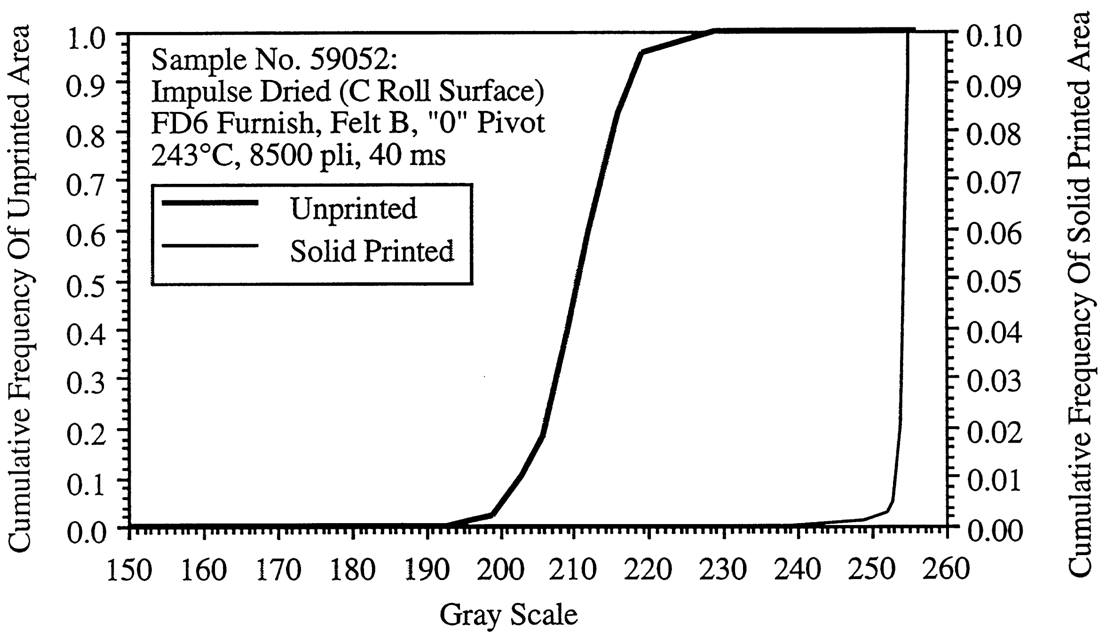

Figure 17. Cumulative Frequency vs. Gray Scale for Printed and Unprinted Regions of a Two-ply Sheet Which Had Been Impulse Dried.

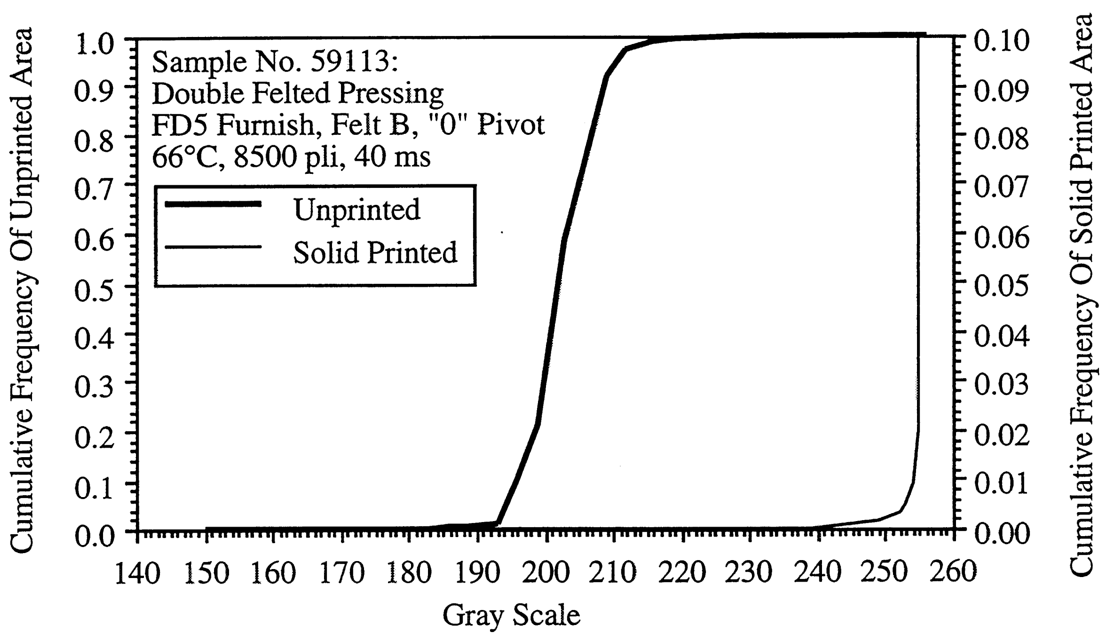

Figure 18. Cumulative Frequency vs. Gray Scale for Printed and Unprinted Regions of a Single-ply 100% OCC Sheet Which Had Been Double Felted Pressed.

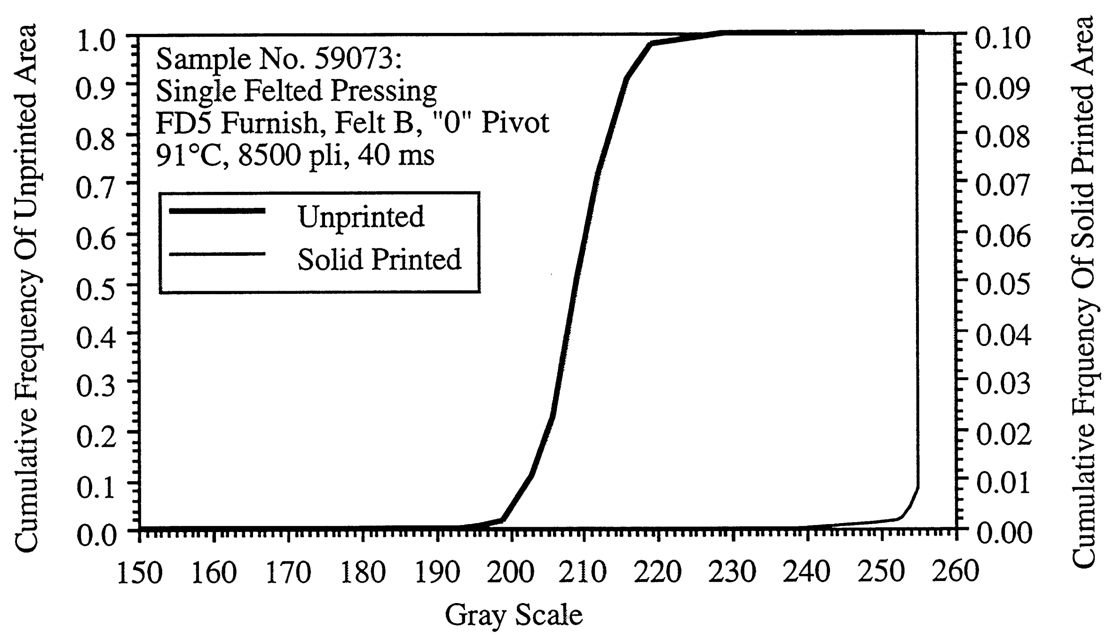

Figure 19. Cumulative Frequency vs. Gray Scale for Printed and Unprinted Regions of a Single-ply 100% OCC Sheet Which Had Been Single-felted Pressed.

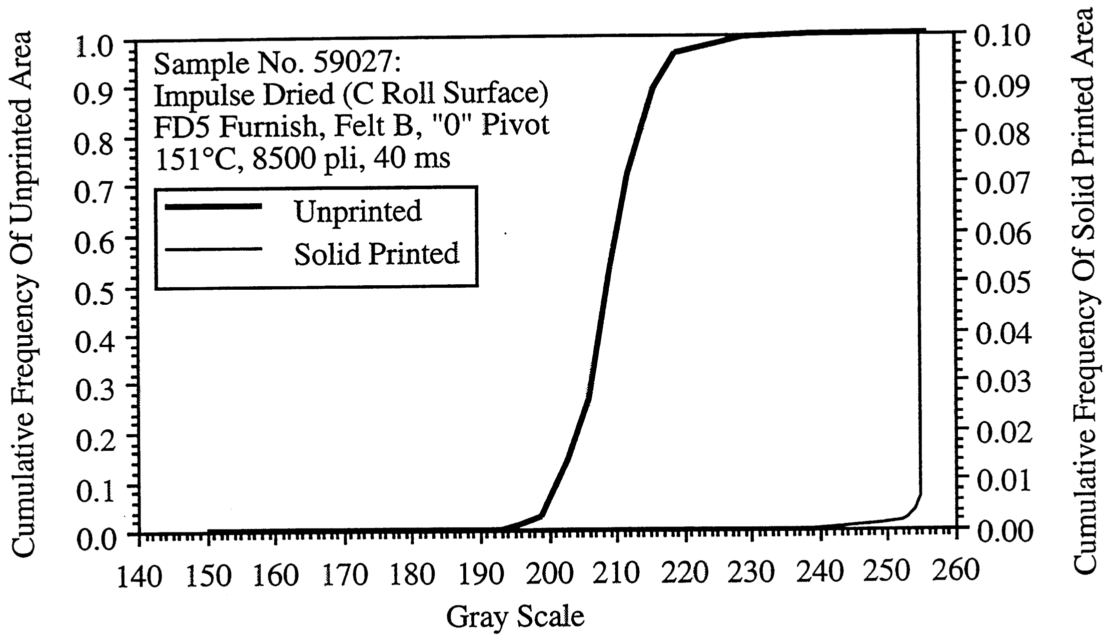

Figure 20. Cumulative Frequency vs. Gray Scale for Printed and Unprinted Regions of a Single-ply 100% OCC Sheet Which Had Been Impulse Dried.

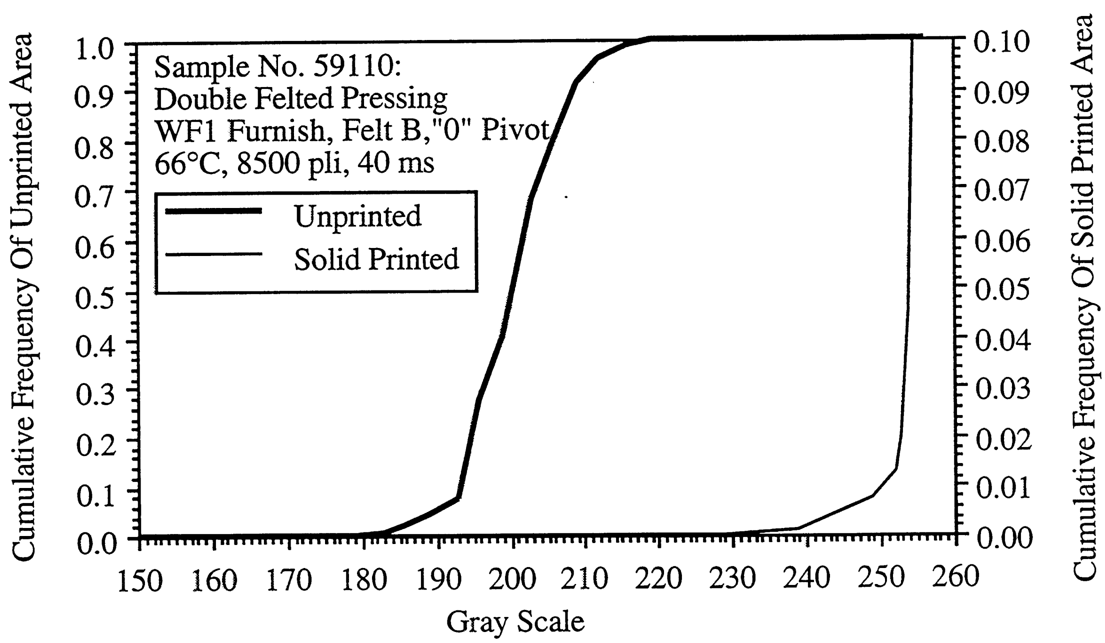

Figure 21. Cumulative Frequency vs. Gray Scale For Printed and Unprinted Regions of a Single-ply 100% Virgin Kraft Sheet Which Had Been Double-felted Pressed.

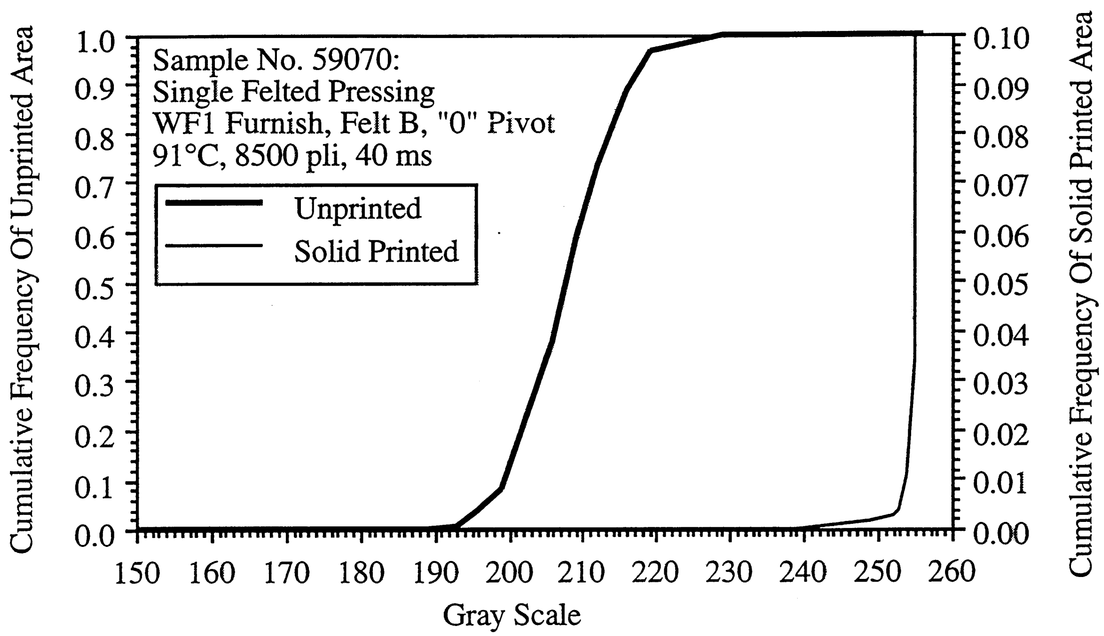

Figure 22. Cumulative Frequency vs. Gray Scale for Printed and Unprinted Regions of a Single-ply 100% Virgin Kraft Sheet Which Had Been Single-felted Pressed.

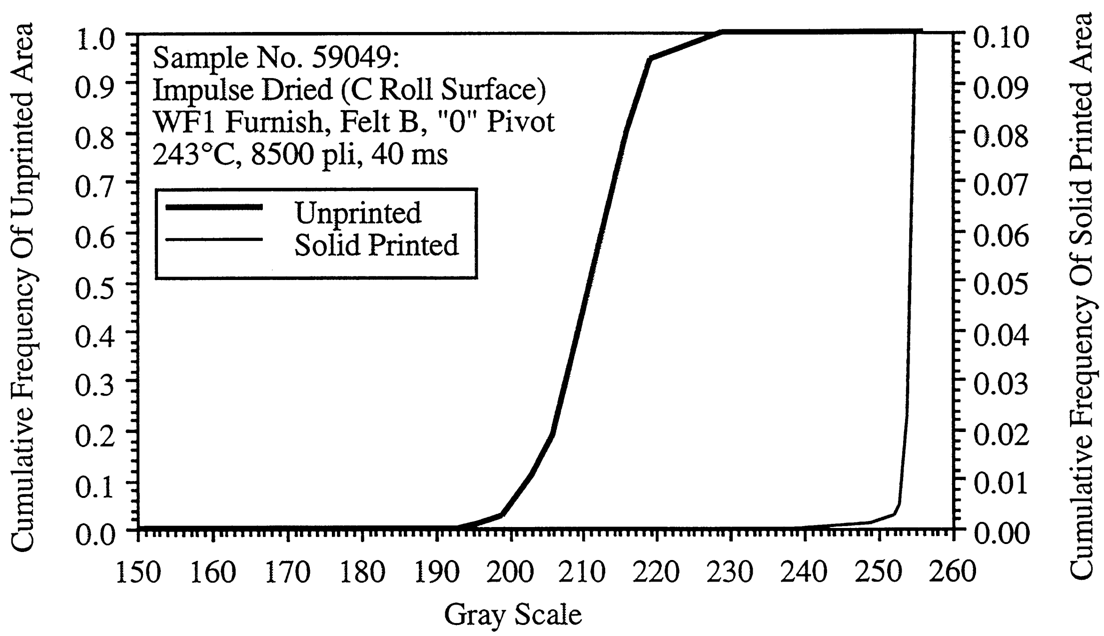

Figure 23. Cumulative Frequency vs. Gray Scale for Printed and Unprinted Regions of a Single-ply 100% Virgin Kraft Sheet Which Had Been Impulse Dried.